March 20, 1964

TO: [redacted]

FROM: [redacted] STAT

SUBJECT: Experimental work relating to the question of anti-reflection coatings

Considerable time during the week of March 20 was spent on tests and experimentation aimed at determining whether to omit anti-reflection coatings from the prototype optical elements. For this purpose the equipment was temporarily assembled with the lenses and substitute plano glass elements located as close as possible to the correct conjugate distances. A low contrast immersed target was used. Visual observations were made and exposures taken on Polaroid and 35 mm film. Tests were made under typical conditions of full coherence and slight departure from complete coherence. These notes are a summary of the work and pertinent results, details of which are contained in Eng. Notebook [redacted] STAT

The Coating Problem

The thought of allowing the lens elements to remain uncoated arose from the desirability of maintaining the glass surfaces as nearly as possible free of the minute defects which cause "artifact" patterns in the image, and from this standpoint it is clearly advantageous to avoid the additional handling and risk involved in coating. On the other hand, absence of the coatings will accentuate interference patterns and ghost images. It will also result in increased exposure time and may result in a measurable loss of contrast at the image.

The types of false imagery involved in the present question fall generally into the following categories:

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a. Ghost images. These are reflected real images, generally of the laser pin-hole position, which happen to focus near the focal plane.

b. Large-pattern interference bands, resulting from interference between plano parallel faces such as the two sides of a glass plate.

c. Sphero-interference patterns - small concentric patterns resulting from interference between reflections from various spherical lens surfaces.

d. "Artifact" patterns - small patterns arising from diffraction at dust particles or lens defects.

The first three of the above image types are prominent in the absence of anti-reflection coatings. The type "d" patterns above are not caused by reflection but when due to small particles are of an average size and appearance very similar to the type "c"; however, they have a characteristic ring intensity distribution resulting from their origin as a convolution of the aperture function with the particle disturbance (Ref. 1) and are thus distinguishable by appearance from the type "c" patterns.

Images in Coherent Light

A number of observations was made visually using ground acetate film at the format plane; however such observation is of limited experimental value since the grain of the film limits visual acuity and most importantly, many types of images which are prominent in photos simply do not show up on the ground film. Results relating to imagery reported in these notes are based on photographs.

The optical elements used in the present setup were all uncoated, with the exception of the liquid film gate plates.

A preliminary exploration of the open spaces along the optical axis revealed surprisingly few actual ghost images. A sharp image 3-1/2 inches ahead of the collimator lens was shown to be due to focusing of the pinhole by internal reflection in the lens, (this lens should certainly be coated). Another pinhole image, probably harmless, was found two inches beyond lens No. 2. The one very objectionable ghost image happened to focus at a point about 2 feet beyond the film plane, but was still sufficiently concentrated at the film to produce a strong image. Furthermore, it was accompanied by a pair of satellites shown to arise from reflections between the two faces of the spatial filter plate and a concave lens surface, (probably the last surface in lens No.2).

Examination of the photos taken under full coherence shows all of the four above named spurious image types to be painfully present. A large (type "b", above) concentric pattern was traced to the simulated spatial filter plate, and disappeared from the photos when this was removed, as did two of the three (type "a") ghost images. There then remained, however, a plethora of defects of the remaining two types ("c" and "d") in such profusion that the entire field appeared covered with overlapping patterns, and no part of the format was free of the crossing fringes, forming a noise background which obscured all detail finer than about 32 mm^{-1}.

An observation of probable significance is this: in the photos taken with prototype optics, which were uncoated but carefully cleaned, type "c" (aphero interference) patterns greatly predominated in number, whereas in recent photos taken on the breadboard, which has coated but by this time quite contaminated optics, the reverse is true.

Images at Reduced Coherence

Subsequent observations and photos were made under conditions of slight departure from the full coherence ordinarily provided by the laser. The mechanism for reducing coherence consisted of a special sandwiched ground glass rotating diffuser (previously described) placed at the position nominally occupied by the pinhole, which was removed, and two layers of clear plastic sheet required to prevent streaking. This optical device results in a reimaged spot size at the transform plane of 0.12-inch diameter. On the basis of a 220 mm^{-1} maximum frequency represented by a 2.52-inch diameter filter plane aperture, this represents less than 5 percent departure from a laterally coherent beam.

Exposures were repeated in the same sequence used in the previous set -- and a startling difference observed: All of the image defects of type "c" and "d" have disappeared. What remains is a single large type "b" pattern covering most of the field, and a single ghost image, greatly reduced in intensity. The "b" pattern disappears when the filter plate is removed. In other words, the coherence reduction of less than 5 percent has completely removed the background "noise" producing disturbances, leaving only two relatively minor defects of types quite amenable to control by coating.

Of course, it has been observed for some time that removing the laser coherence by the use of a ground glass prevents the defect disturbances. What is brought out here is the very small amount of departure from full coherence required for effective control.

Transmission and Scattering

The transmission of the laser beam through lenses No. 1 and No. 2 in tandem was measured at 42.8 percent, which agrees with the theoretical value for the 20 uncoated surfaces. This indicates that, for the system, exposure times would be cut to less than half by coating all or most of the surfaces.

In order to get some measure of the contrast reduction caused by scattering in the uncoated lenses, a mask was cut with a circular aperture slightly larger than the diameter of the emergent cone at the last surface of the camera (No. 2) lens or about 3 inch diameter. Since the total clear aperture of the last element is over 6 inches, this should cut out about 3/4 of the general scattered illumination falling on the focal plane, while allowing transmission of a full pencil to the center of the format. Photos were taken, using a 35 mm camera back, of the critical areas of the low contrast target. These transparencies are now awaiting evaluation by means of the microdensitometer to determine whether a measurable difference in contrast exists due to presence or absence of a considerable portion of the scattered light.

Conclusions

A few miscellaneous observations have resulted from the investigation — for example, it appears highly important that any glass used in the filter plane be given the best possible coating; also, the film gate and collimator glass

should certainly be coated. Aside from these, the question of coating the entire system will be colored by the following observations.

a. Using purely coherent light it appears certain that the image plane will always be afflicted with a dense background of noise from several types of sources, even in spite of the most careful precautions in regard to lens handling, etc., whether or not the system is coated, and to an extent which would preclude use of the system for its intended purpose.

b. A very minor departure from full coherence is sufficient to control the worst and most abundant sources of noise, and will in all probability be resorted to in the practical application of the equipment.

This being the case, it would seem a logical step to risk the slight addition of lens artifacts of a type whose effects are rather easily controllable through measures which must be taken in any case, and thereby gain the numerous advantages of coating.